Exhibition 2

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Wireless Communications

PRINCIPLES AND PRACTICE

Second Edition

THEODORE S. RAPPAPORT

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WIRELESS COMMUNICATIONS

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SECOND EDITION

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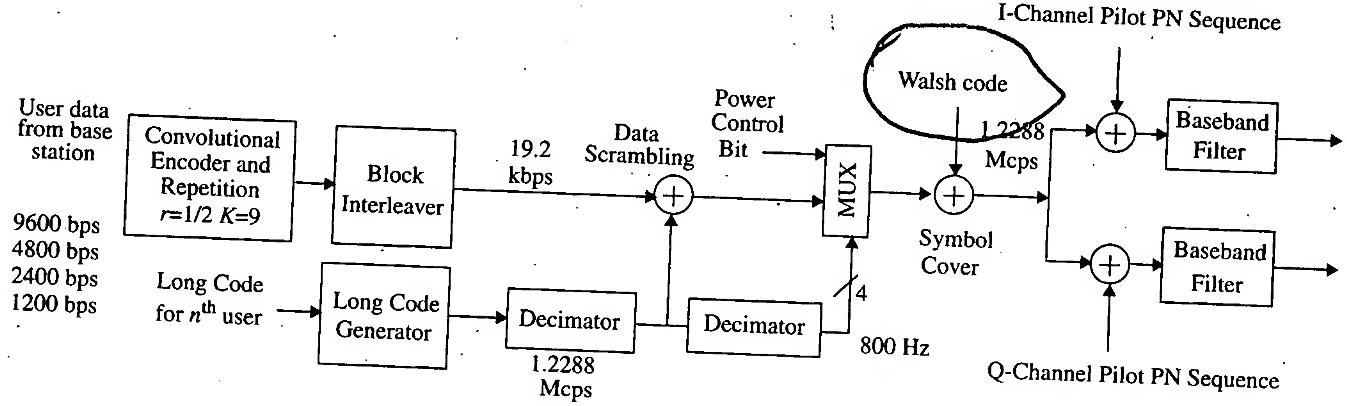

Figure 11.14 Forward CDMA channel modulation process.

The speech encoder exploits pauses and gaps in speech, and reduces its output from 9600 bps 1200 bps during silent periods. In order to keep a constant baseband symbol rate of 19.2 kbps, henever the user rate is less than 9600 bps, each symbol from the convolution encoder is repeated efore block interleaving. If the information rate is 4800 bps, each code symbol is repeated one me. If the information rate is 2400 bps or 1200 bps, each code symbol is repeated three or seven mes, respectively. The repetition results in a constant coded rate of 19,200 symbols per second for ll possible information data rates.

11.4.2.2 Block Interleaver

After convolution coding and repetition, symbols are sent to a 20 ms block interleaver, which is a 24 by 16 array.

11.4.2.3 Long PN Sequence

In the forward channel, direct sequence is used for data scrambling. The long PN sequence is uniquely assigned to each user is a periodic long code with period 2^{42}-1 chips. (This corresponds to repeating approximately once per century.) The long code is specified by the following characteristic polynomial [TIA93]

$$p(x) = x^{42} + x^{35} + x^{33} + x^{31} + x^{27} + x^{26} + x^{25} + x^{22} + x^{21} + x^{19} + x^{18} + x^{17} + x^{16} + x^{10} + x^{7} + x^{6} + x^{5} + x^{3} + x^{2} + x^{1} + 1$$

Each PN chip of the long code is generated by the modulo-2 inner product of a 42 bit mask and the 42 bit state vector of the sequence generator. The initial state of the generator is defined to be when the output of the generator becomes '1' after following 41 consecutive '0' outputs, with the binary mask consisting of '1' in the most significant bit (MSB) followed by 41 '0's.

Two types of masks are used in the long code generator: a public mask for the mobile station's electronic serial number (ESN) and a private mask for the mobile station identification number (MIN). All CDMA calls are initiated using the public mask. Transition to the private mask is carried out after authentication is performed. The public long code is specified as follows: M_{41} through M_{32} is set to 1100011000, and M_{31} through M_0 is set to a permutation of the mobile station's ESN bits. The permutation is specified as follows [TIA93]:

$$\text{ESN} = (E_{31}, E_{30}, E_{29}, E_{28}, E_{27}, \ldots\ldots\ldots E_3, E_2, E_1, E_0)$$

$$\text{Permuted ESN} = (E_0, E_{31}, E_{22}, E_{13}, E_4, E_{26}, E_{17}, E_8, E_{30}, E_{21}, E_{12}, E_3, E_{25}, E_{16}, E_7, E_{29}, E_{20}, E_{11}, E_2, E_{24}, E_{15}, E_6, E_{28}, E_{19}, E_{10}, E_1, E_{23}, E_{14}, E_5, E_{27}, E_{18}, E_9)$$

The private long code mask is specified so M_{41} and M_{40} are set to '01', and M_{39} through M_0 are set by a private procedure. Figure 11.15 illustrates the long code mask format.

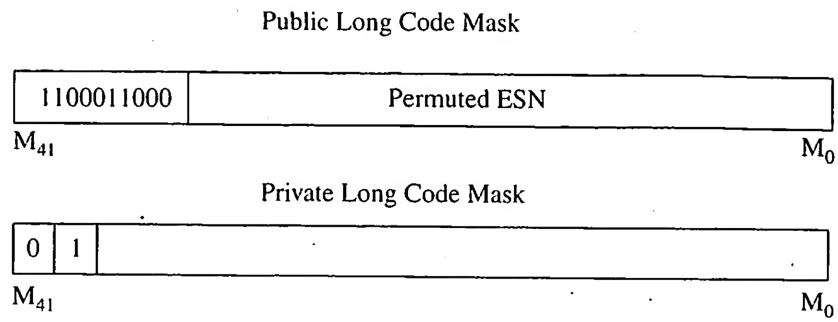

Figure 11.15 Long code mask format for IS-95.

11.4.2.4 Data Scrambler

Data scrambling is performed after the block interleaver. The 1.2288 MHz PN sequence is applied to a decimator, which keeps only the first chip out of every sixty-four consecutive PN chips. The symbol rate from the decimator is 19.2 ksps. The data scrambling is performed by modulo-2 addition of the interleaver output with the decimator output symbol as shown in Figure 11.14.

11.4.2.5 Power Control Subchannel

To minimize the average BER for each user, IS-95 strives to force each user to provide the same power level at the base station receiver. The base station reverse traffic channel receiver estimates and responds to the signal strength (actually, the signal strength and the interference) for a particular mobile station. Since both the signal and interference are continually varying, power control updates are sent by the base station every 1.25 ms. Power control commands are sent to each subscriber unit on the forward control subchannel which instruct the mobile to raise or lower its transmitted power in 1 dB steps. If the received signal is low, a '0' is transmitted over the power control subchannel, thereby instructing the mobile station to increase its mean output power level. If the mobile's power is high, a '1' is transmitted to indicate that the mobile station should decrease its power level. The power control bit corresponds to two modulation symbols on the forward traffic channel. Power control bits are inserted after data scrambling as shown in Figure 11.16.

Power control bits are transmitted by using puncturing techniques [TIA93]. During a 1.25 ms period, twenty-four data symbols are transmitted, and IS-95 specifies sixteen possible power control group positions for the power control bit. Each position corresponds to one of the first sixteen modulation symbols. Twenty-four bits from the long code decimator are used for data scrambling in a period of 1.25 ms. Only the last 4 bits of the 24 bits are used to determine the position of the power control bit. In the example shown in Figure 11.16, the last 4 bits (23, 22, 21, and 20) are '1011' (11 decimal), and the power control bit consequently starts in position eleven.

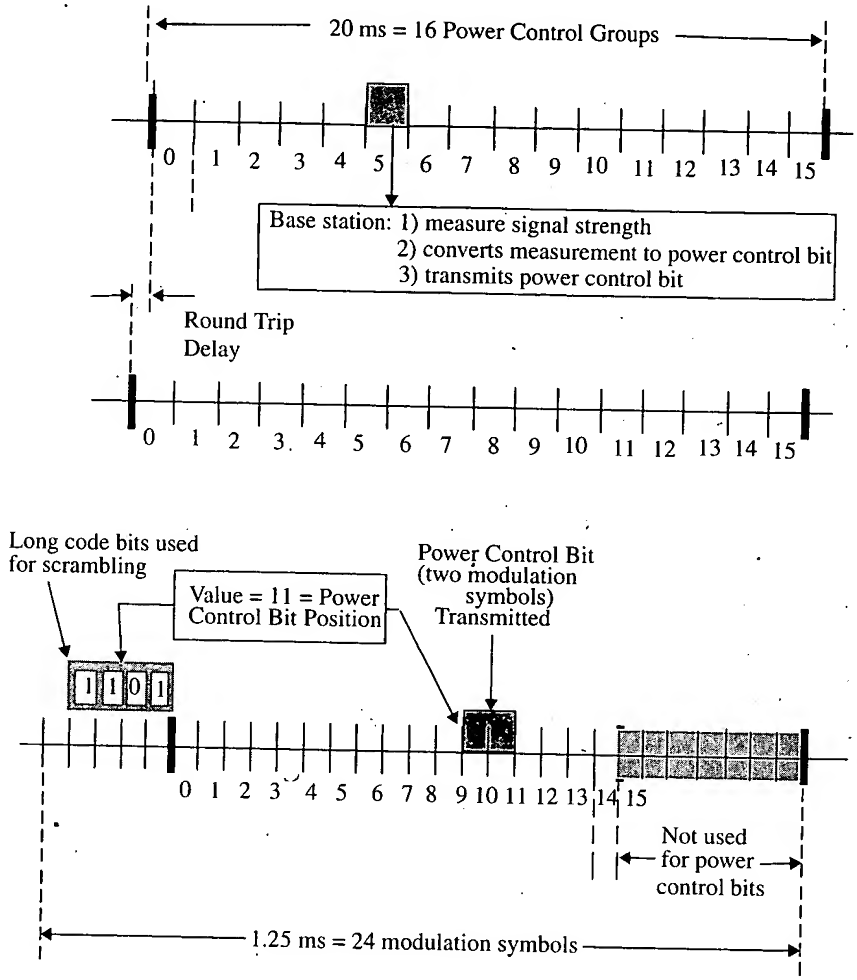

Figure 11.16 Randomization of power control bit positions in a IS-95 forward traffic channel.

11.4.2.6 Orthogonal Covering

Orthogonal covering is performed following the data scrambling on the forward link. Each traffic channel transmitted on the forward CDMA channel is spread with a Walsh function at a fixed chip rate of 1.2288 Mcps. The Walsh functions comprise of sixty-four binary sequences, each of length 64, which are completely orthogonal to each other and provide orthogonal channelization for all users on the forward link. A user that is spread using Walsh function n is assigned channel number n (n = 0 to 63). The Walsh sequence repeats every 52.083 μs, which is equal to one coded data symbol. In other words, each data symbol is spread by 64 Walsh chips.

The 64 by 64 Walsh function matrix (also called a Hadamard matrix) is generated by the following recursive procedure:

$$H_1 = 0 \qquad H_2 = \begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix}$$

$$H_4 = \begin{matrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{matrix} \qquad H_{2N} = \begin{matrix} H_N & H_N \\ H_N & \overline{H_N} \end{matrix}, \text{ where } N \text{ is a power of 2.}$$

Each row in the 64 by 64 Walsh function matrix corresponds to a channel number. For channel number n, the symbols in the transmitter are spread by the sixty-four Walsh chips in the nth row of the Walsh function matrix. Channel number 0 is always assigned to the pilot channel. Since Channel 0 represents Walsh code 0, which is the all zeros code, then the pilot channel is nothing more than a "blank" Walsh code and thus consists only of the quadrature PN spreading code. The synchronization channel is vital to the IS-95 system and is assigned channel number 32. If paging channels are present, they are assigned to the lowest code channel numbers. All remaining channels are available for forward traffic channels.

11.4.2.7 Quadrature Modulation

After the orthogonal covering, symbols are spread in quadrature as shown in Figure 11.14. A short binary spreading sequence, with a period of 2^{15}-1 chips, is used for easy acquisition and synchronization at each mobile receiver and is used for modulation. This short spreading sequence is called the pilot PN sequence, and it is based on the following characteristic polynomials:

$$P_I(x) = x^{15} + x^{13} + x^9 + x^8 + x^7 + x^5 + 1$$

for the in-phase (I) modulation and

$$P_Q(x) = x^{15} + x^{12} + x^{11} + x^{10} + x^6 + x^5 + x^4 + x^3 + 1$$

for the quadrature (Q) modulation.

Based on the characteristic polynomials, the pilot PN sequences $i(n)$ and $q(n)$ are generated by the following linear recursions:

$$i(n) = i(n\text{-}15) \oplus i(n\text{-}10) \oplus i(n\text{-}8) \oplus i(n\text{-}7) \oplus i(n\text{-}6) \oplus i(n\text{-}2)$$

$$q(n) = q(n\text{-}15) \oplus q(n\text{-}13) \oplus q(n\text{-}11) \oplus q(n\text{-}10) \oplus q(n\text{-}9) \oplus q(n\text{-}5) \oplus q(n\text{-}4) \oplus q(n\text{-}3)$$

where the in-phase and quadrature PN codes are used respectively, and $\oplus$ represents modulo-2 addition. A '0' is inserted in each sequence after the contiguous succession of fourteen '0's to generate pilot PN sequences of length 2^{15}. The initial state of both I and Q pilot PN sequences is defined as the state in which the output of the pilot PN sequence generator is the first '1' output